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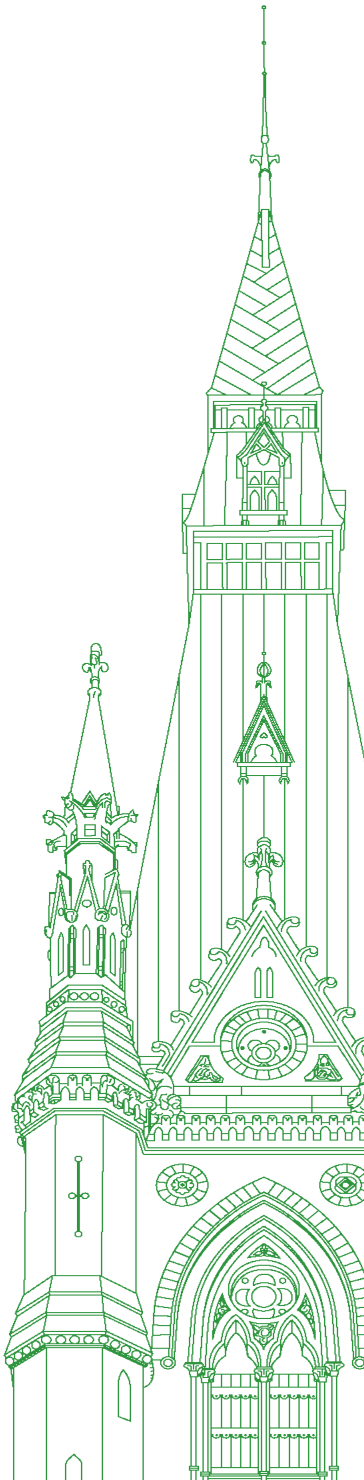

Chair: Mr. Joël Lightbound

Standing Committee on Industry and Technology

Tuesday, March 29, 2022

● (1540)

[*Translation*]

The Chair (Mr. Joël Lightbound (Louis-Hébert, Lib.)): Good afternoon to all.

I see that all members are present. I therefore call the meeting to order.

First of all, I'd like to apologize to the witnesses. We are starting the meeting nine minutes late because of a vote in the House.

Welcome to the fourteenth meeting of the House of Commons Standing Committee on Industry and Technology.

Pursuant to Standing Order 108(2) and the motion adopted by the committee on Tuesday, March 1, 2022, the committee is meeting to study quantum computing.

Today's meeting is taking place in a hybrid format, pursuant to the House order of November 25, 2021. Members may attend in person or by Zoom. Those who are attending in person know the public health rules in place, so I am asking them to behave accordingly.

Today we are pleased to welcome Dr. Raymond Laflamme, professor of physics, Canada Research Chair in Quantum Computing at the University of Waterloo.

We also welcome Dr. Alireza Yazdi, chief executive director of Anyon Systems, Dr. Philippe St-Jean, chief executive officer of Nord Quantique, and Mr. Rafal Janik, head of product at Xanadu Quantum Technologies.

Thank you for being with us.

Dr. Laflamme, you have the floor for about six minutes.

Dr. Raymond Laflamme (Professor of Physics, Canada Research Chair in Quantum Computing, University of Waterloo, As an Individual): Good afternoon.

I thank the members of the committee for their interest in the field of quantum information and related technologies. I also thank them for inviting me to say a few words on the subject. This committee is really important for the Government of Canada to build on its early success in this area.

On Friday, my colleagues Alexandre Blais, Norbert Lütkenhaus and Barry Sanders gave you an introduction to quantum information. So I won't repeat what they said, because they did an excellent job. However, I would like to emphasize two things that were mentioned on Friday that I think are really important in understanding and situating quantum information and technologies in Canada.

First, the discipline of quantum information is broad. It's about how the universe we live in behaves on a microscopic scale, it's about quantum cryptography in the context of national security, and it's about the development of technologies for extracting natural resources or solving health-related problems, for example. The expertise gained in quantum information could therefore represent an economic benefit in the 21st century.

Second, quantum information initiatives in Canada and elsewhere in the world are really moving at the speed of a marathon, not a sprint. Although the discipline is still young, the race is already on.

[*English*]

Quantum information science and technology is an incredible opportunity for Canada. We have been successful at putting Canada on the international map in the last 20 years, but we cannot sit on our laurels. The late Tom Brzustowski, past president of NSERC, whom I met in the early 2000s and who became one of my mentors, used to quote an American technologist who said again and again that Canada never misses an opportunity to miss an opportunity.

I hope that with quantum we will prove him wrong. This can happen only if there is a team effort. That includes the community, of course, from the government, industry, and academia, but also everybody who is around the table today.

[*Translation*]

I will now tell you a little about myself. I was born in Quebec City. I did a bachelor's degree at Laval University, a doctorate at Cambridge University under the supervision of Dr. Stephen Hawking, and a Killam postdoctoral fellowship at the University of British Columbia. I returned to Cambridge for two years before spending ten years at Los Alamos National Laboratory in the United States.

In 2001, I was recruited by Dr. David Johnston and Dr. Mike Lazaridis to build the Institute for Quantum Computing in Waterloo, with the support of the Canada Research Chairs and the Canada Foundation for Innovation, or CFI, programs, and to put Canada on the map in this area.

[*English*]

I led the institute until 2017, and that was for 15 years. The goal was to develop a multidisciplinary institute to push the boundaries of science and develop corresponding technologies.

The institute had the goals of becoming a world leader in research in quantum computing, beginning to develop a workforce that understands and can develop quantum technologies and to communicate the science and engineering to a broad audience. The institute, called IQC for short, is one of the pillars of the quantum valley ecosystem that has been built for the last 20 years.

The other partner organizations are the Perimeter Institute, the quantum-nano fabrication facility, the conformative quantum technologies program from the Canada first research excellence fund, the Ideas Lab, which prototypes emerging quantum technologies and, finally, Quantum Valley Investments, which helped commercialize the fund and the start-ups that come out of the research.

I believe that building ecosystems is important to sustain the path from quantum ideas to quantum technologies with societal impact. The path is a long chain with many links, and any broken parts bring challenges to reach the end point. As you heard on Friday, the concept of quantum ecosystems has also been adopted by Sherbrooke and Calgary, and there are hints that Vancouver will also build its own in the near future. I believe that an important role of the national strategy will be to nurture and help develop them.

I have also been the director of the quantum information program at CIFAR, the Canadian Institute for Advanced Research for 15 years. There the goal was to study fundamental aspects of quantum computing. The program brought two dozen of the best researchers in quantum information both in Canada and across the world. The program is still running, and it is a success being led by Aephraim Steinberg.

The quantum community also put together an NSERC network called the nano innovation platform in 2006. The program, Quantum Works, brought industry, government and academic researchers together, and can be thought of as the grandparent of the present national strategy.

I'd like to finish by commenting on points where the national quantum strategy should have some focus. One, de-risk quantum technologies or help to do so; two, be strategic and make choices, as there are many opportunities but the resources are, as usual, limited; three, de-silo our environment to develop a true quantum ecosystem, and we heard that on Friday. Find more ways to facilitate industry, government and academia interaction.

There are already many of these interactions. In fact, my colleagues around the table in the quantum community have some. 1QBit is involved with both Sherbrooke and Waterloo. Anyon Systems are using the Waterloo lab facility. Xanadu has hired many Waterloo grads on its scientific board. Many of these interactions are ad hoc, and strengthening them will increase the chance for Canada to score many goals in the quantum game.

Fourth, develop and maintain the infrastructure to develop quantum technologies, like the fabrication they mention in Waterloo, but there's also one in Sherbrooke and one in Vancouver. Be cognizant and plug the holes in the present funding programs. There needs to be lots of interaction between this national strategy and the community.

Finally, develop talent, including leadership that is cognizant of the field, and by this I mean both in the quantum community itself and on the government side.

● (1545)

It was a surprise when I moved from the U.S. to here to realize that program managers in Canada seem to be a lot more offhand than what I've seen both in the U.S. and in the UK.

I'd like to finish by saying that quantum information science and technology is an incredible opportunity for Canada, and let's capitalize on it.

Thank you.

[*Translation*]

The Chair: Thank you very much for your presentation, Dr. Laflamme. It's an honour to have you here. Your background is quite impressive, frankly.

Dr. Yazdi, you have the floor for six minutes.

[*English*]

Dr. Alireza Yazdi (Chief Executive Director, Anyon Systems Inc.): Thank you, Mr. Chairman and distinguished members of the committee.

[*Translation*]

Thank you for inviting me to appear before the committee.

My name is Alireza Yazdi. I am the founder and chief executive director of Anyon Systems. I am a first-generation immigrant, a scientist and an entrepreneur.

[*English*]

I graduated from McGill with a Ph.D. in engineering, so I'm an engineer by training, not a physicist, with all due respect to other physicists on the panel. I have over 15 years of experience in high-performance computing, out of which the last seven years have been almost entirely focused on building a quantum computer.

Besides my technical work and business, I'm also a student of history and geopolitics. In particular, given my day job, I'm very interested in disruptive technological trends that have geopolitical ramifications.

Before I formally introduce Anyon Systems and talk about what we do, I will take a few moments to provide some background and context for the discussion ahead.

There is a saying in the tech industry, that “data is the new gold”. Companies like Google and Facebook compete on mining this gold. They spend vast resources on data collection, indexing and storage, but data becomes really valuable when it is processed, when it is analyzed. As you know, there is an exponential growth of global data volume, and with that, there is an ever-increasing need for computational power. I do not use the phrase “computational power” lightly, and I do not use it in a mere technical context. When I say “computational power”, I mean power to process data, power to develop new technologies, power to make better decisions and power to stay ahead of the competition. This power is strategic in nature.

Given the data volume and the strategic value of the computational power I mentioned, there is an acute need for new technologies, especially new types of hardware, that can expand our ability to process data, explore nature, invent new technologies and keep our nation safe. Quantum computing is one of the candidate technologies that promises significant computational power, but for only a certain class of problems. Please note that not every problem or every application can necessarily be accelerated using quantum computers.

Let me be more clear. A quantum computer is not a stand-alone computer. A quantum computer is a hardware accelerator. Its job is to accelerate performing some computations for a class of problems that are deemed very valuable.

Having covered that background, let me share with you some background about our company. Anyon Systems was founded in 2014, right around the time that Google and IBM started their quantum hardware effort. In fact, despite being barely eight years old, it is one of the oldest quantum computing hardware companies in the world. Our mission is to develop and commercialize logic-based universal quantum computers.

Over the past eight years, Anyon has developed the full vertical hardware stack of superconducting quantum computers. In fact, to my best knowledge, we are the only company in the world that makes all major components of a superconducting quantum computer in house, including the superconducting quantum processor itself, the cryogenics systems, reaching temperatures of only a few millikelvins above absolute zero, the control electronics and the software stack to use the machine.

Developing such unique expertise has enabled us to be largely independent from foreign suppliers and make sure that Canada will have indigenous and domestic capabilities. Our quantum computing systems are almost entirely manufactured and assembled at our facilities here in Montreal and in Waterloo. We have built valuable partnerships with key stakeholders in government and academia, and we strive to help build ecosystems by providing hardware access to Canadian researchers.

In 2020, we received a contract through the build in Canada innovation program to deliver a quantum computer for testing by Defence Research and Development Canada, DRDC. Despite the challenges posed by the COVID-19 pandemic, I'm glad to inform you that the machine was completed and went online in 2021. We are proud to announce that this machine is Canada's first gate-based quantum computer. The key performance metrics exceed those of some of the most well-known actors in the industry, and on many key metrics it is second only to Google.

Last fall, I also had the pleasure of delivering a series of lectures to the talented researchers of DRDC and other government agencies. The goal of this lecture series was to help government researchers adopt quantum computing and start doing great research in the field.

More recently, we received a second order to deliver a state-of-the-art machine to one of Canada's largest high-performance computing centres. This machine will enable Canadian researchers, both in academia and industry, to have early access to a highly sought-after technology, enabling them to further build novel algorithms and perform cutting-edge research.

While we currently deliver small- to intermediate-scale machines that are tailored for early adopters, Anyon's overarching goal is to deliver what we called a utility-scale quantum computer, a quantum computer that provides computational value more than its cost.

Our team has developed a detailed technological road map to that effect, and we have been inventing very novel technologies to reach our milestones.

Before I conclude my remarks, I would be remiss if I did not thank the kind and generous support that we have received over the past few years from the National Research Council of Canada, especially through IRAP; the Institute for Quantum Computing at the University of Waterloo, especially the management and staff of Waterloo's quantum-nano fabrication facility; and the Ministère de l'Économie et de l'Innovation here in Quebec.

Once again, I thank you for this invitation and I look forward to our discussion.

● (1550)

The Chair: Thank you very much, Mr. Yazdi.

I'll now turn to Mr. St-Jean for six minutes.

[*Translation*]

Dr. Philippe St-Jean (Chief Executive Officer, Nord Quantique): Good afternoon.

I would like to thank the members of the committee for the opportunity to speak with you today.

My name is Philippe St-Jean, and I am the chief executive officer and co-founder of Nord Quantique, a company that designs and manufactures an error-tolerant quantum computer. We come from the centre of excellence in quantum technology at the Université de Sherbrooke, the Institut quantique. It's headed by Dr. Alexandre Blais, who appeared before this committee last week.

Several of the witnesses who have presented their views to this committee have already made it clear that Canada has an interest in promoting the development of its expertise in quantum computing. I will therefore focus on the aspects that specifically concern the development of these computers within Canadian companies already engaged in this field.

As mentioned earlier, Canada can be proud of the quality of academic research in quantum computing that is taking place in our centres of excellence. The challenge now is to ensure that this expertise also translates into industrial and commercial success, and thus to establish what should be the federal government's roadmap in this direction.

Our needs can be broken down into two points.

Obviously, we need access to the necessary funds to develop this technology, especially since we are competing with ambitious programs put forward by other governments elsewhere in the world.

More importantly, our future success will depend on the support of the ecosystems surrounding the centres of excellence in quantum technology from which we are emerging. Leased access to state-of-the-art infrastructure and laboratories, the specialized equipment there, the experts who work there and their knowledge, and the young talent who develop there and grow our ranks is key to success. For us, this is the Canadian approach. This collaboration has allowed us to remain competitive despite the considerable private sector investment in our international competitors.

The crucial contribution of these centres of excellence was brilliantly described and highlighted by Dr. Laflamme at a recent conference organized by NanoCanada, Quantum Days. I invite the members of the committee to watch or rewatch this presentation.

Let's face facts about the Canadian commercial quantum sector. We all have a difficult road ahead of us. All companies developing quantum computers are facing a dry spell in which they must develop the technology without being able to sustain the effort with sufficient short-term revenues. It is therefore critical that the government act and help us, either directly as a first user of the prototype computers we are developing, or as an intermediary by facilitating its access to the early user and scientific community in Canada.

It is also important that this support be effective and agile. Unfortunately, the constraints of existing programs can sometimes create excessive delays.

The risk, for example, is that in the time between the submission of a good project, its evaluation, its approval and access to funds, the project itself may have lost relevance, as things move very fast in this sector.

The scale at which these projects are funded should be comparable to that enjoyed by our international competitors in their respective countries.

Finally, we also need to help change the mindset of Canadian private investors so that they understand that they have everything to gain by placing part of their investments into longer-term breakthrough technologies. That's how we need to think.

I'd like to end on an optimistic note. Last week, Dr. Alexandre Blais emphasized to this committee the importance of managing expectations, noting that we cannot do everything in Canada and that we must therefore focus our efforts intelligently. For us, this means that it is important to support our centres of excellence, but above all to foster the development of ecosystems around these centres, which in turn provide fertile ground for emerging Canadian companies in the quantum sector.

I want to emphasize one important point. This management of expectations does not mean that Canada is limited to a background or ancillary role in the development of the first error-tolerant commercial quantum computers. Canada is truly in this race and is in a very good position. Based on the current situation and status, we can confidently say that the first commercially viable quantum computers will emerge in two countries, Canada and the United States. For this scenario to become a reality, we must act now to support this transition from scientific research to the industrial and commercial development of this technology.

● (1555)

The Chair: Thank you very much, Dr. St-Jean.

Mr. Janik, you now have the floor for six minutes.

[*English*]

Mr. Rafal Janik (Head of Product, Xanadu Quantum Technologies Inc.): Thank you, Mr. Chairman.

I would like to thank the committee for inviting me here and for giving me the opportunity to speak on what is a very important topic, namely, how do we keep the strategic lead we have in quantum technologies here in Canada into the future?

I and my colleagues, many of whom have spoken to the committee already, have really addressed the fact that we've enjoyed close to 25 years now of really fantastic support and funding across quantum sciences and quantum information, and now even through the commercialization of quantum technologies. The end goal of this has really been identified as building and developing a large-scale quantum computer. We've heard a couple of different names for this economically viable quantum computer, but really what we're referring to is a quantum computer with millions of physical qubits, a technology that can solve the world's most challenging problems. This is the goal of many other people that you may have heard from already.

Xanadu is on this path. Our mission is to build fault-tolerant universal quantum computers. We are now a six-year-old company based in the heart of Toronto, with over 120 employees working on this mission. The majority of us are focused on building the fundamental photonic hardware to deliver this quantum computer, but we also work on the software stack, which is really important in making sure we get full adoption of this technology as it becomes viable.

To date, we have stood up online seven unique quantum computers across 15 different quantum processing unit generations. We've gone through 15 different manufacturing cycles with partners across the world. All of this is developed directly in our Toronto facility, which is the world's most advanced nano-photonics facility.

Approximately every six months, we are doubling the qubit count, increasing exponentially the computational power of a quantum computer, but it is important to note that these quantum computers are still far away from delivering on that true economic value. We believe the photonics platform has a unique opportunity here over some other approaches to be able to do this, but of course the jury is still out, and we do not believe this will be a winner-take-all scenario.

The reason that photonics represents such a unique opportunity for quantum technologies is that it's already a technology that is well understood in our telecommunications and data communications world. The chips that we develop are easily manufacturable at scale, which is one of the things you will need to develop a large-scale, fault-tolerant quantum computer.

They also operate at room temperature. Ninety per cent of our current system operates at 20°C, which means you're able to iterate and develop a lot faster and more cheaply. Not unique to us, but definitely with my colleagues at Nord Quantique, different architectures provide unique opportunities for some of the biggest challenges in correcting errors and ensuring that quantum computers are fault-tolerant.

With all of this put together, I will maybe highlight for the committee that there are many different approaches to building a quantum computer. Each comes with its own advantages and disadvantages. I'd also like to mention that we have one of the leading software platforms out there, in PennyLane. This is an open-source, general-purpose quantum computing tool that is competing right now on par with those from IBM, with Qiskit, and from Google, with SIRC.

Our approach is a bit different. We've taken a fully community open-source approach. Not only do we have corporate partners that are co-developing this tool with us; we also have academics across Canada and across the world. As of this year, it's also become fundamental coursework across a few universities. We're working with the Quantum Algorithms Institute in British Columbia to also ensure that they'll be able to provide further training and resources for the workforce as we continue to build it.

There's one final thing I'd like to point out about our core approach to building a quantum computer. As it is based on photonics, it also offers unique opportunities for quantum sensing and quantum communication. Today we have a test bed network that's been deployed for quantum communication and quantum key distribution here in our lab in Toronto. We've also been developing quantum sensing solutions for the National Research Council through the Innovative Solutions Canada project.

With that, I'd like to thank the committee one more time. I'd be pleased to answer any questions the committee may have.

● (1600)

[*Translation*]

The Chair: Thank you very much, Mr. Janik.

We'll now go to the first round of questions.

Mr. Deltell, you have the floor for six minutes.

Mr. Gérard Deltell (Louis-Saint-Laurent, CPC): Thank you very much, Mr. Chair.

Good afternoon, colleagues.

I thank all the witnesses for taking part in this discussion. It is very impressive to have so many talented people come before the committee. It's a privilege for us as parliamentarians, and it's a gift to all Canadians.

I have a couple of issues to address: choices, labs and funding. I'll talk about the choices right away.

Dr. Laflamme, first of all, I would like to greet you as a citizen of Quebec City. It is always nice to have colleagues from the same part of the country. You mentioned earlier that Canada had to make choices and that it was impossible to do everything.

In your opinion, what sectors should we prioritize in the immediate future?

Dr. Raymond Laflamme: In my opinion, among the various choices Canada can make, the stimulation of quantum ecosystems in the country should be the priority.

There are different ways of giving funds to organizations, but it must be done in a holistic way. You have to make sure you cover all the links, from basic science to commercialization. You need a group of people to make sure that all the links are connected and that none are broken.

I think this is a natural choice, as ecosystems are already emerging in many parts of Canada. All Canadian companies that turn to quantum information can benefit from these ecosystems.

● (1605)

Mr. Gérard Deltell: Thank you very much, Dr. Laflamme.

I will now ask the same question of Dr. St-Jean.

Dr. St-Jean, you said that you have already targeted certain sectors that are more promising than others.

Canada can't do everything, but in your experience, what are the essential choices that Canada must make to be able to compete in the world?

Dr. Philippe St-Jean: The emerging companies that are dedicated to quantum computing and that are trying to design and build a quantum computer need financial resources, but also the support of an ecosystem. You have to understand that it's not easy to build a quantum computer. It is a very difficult task for these companies.

This is in contrast to what we see in other sectors, such as artificial intelligence, or the software-as-a-service model, or SaaS. One can imagine many emerging companies in these areas starting their business in a garage. However, the same is not at all possible in quantum computing.

You need access to this expertise. There is no doubt that we benefit from our strategic positioning in the Sherbrooke ecosystem. We need the expertise of the Institut quantique at the Université de Sherbrooke.

We are looking at three poles. At present, we are conducting activities at the Institut quantique at the Université de Sherbrooke. Our processors are manufactured at the Institut interdisciplinaire d'innovation technologique, which does microelectronics prototyping. This institute, which is not very far from here, is attached to the Université de Sherbrooke. We are also thinking of eventually using the facilities at the MiQro Innovation Collaboration Center, or C2-MI, in Bromont, which provides prototyping tools, but of an industrial nature. This would allow us to have industrial quality tools.

This access is essential for us. This is how we operate at present and it allows us to move forward. It is obvious that we could not fund this infrastructure ourselves. We are happy to rent this equipment and contribute our expertise to this community. If we didn't have this whole ecosystem supporting us, I don't see how we could do it.

Mr. Gérard Deltell: I like your reference to the garage. Everyone knows the very romantic story of Apple, a company that was born in a garage in Silicon Valley. That's where the first Apple computer was made. You're telling me that the same is true of Amazon. I'm going to have to broaden my knowledge. We're all going to have to buy a garage to create something. Anyway, we understand that you need equipment.

Dr. Yazdi, your company is one of the oldest, if I may say so. What equipment do you need in this area?

You know better than I do that today's equipment will be outdated in two years. What investments do you need to make, and how much funding do you need to get the necessary equipment to conduct research in your private company?

[*English*]

Dr. Alireza Yazdi: Is the question for me?

Mr. Gérard Deltell: My question is for you, Mr. Yazdi. As your business has been established for many years, I was wondering what kind of equipment you needed. What was the hardware you needed to develop your business, your company? How much did you have to invest? What kind of role could the private sector play in your business?

● (1610)

Dr. Alireza Yazdi: I think the part that any company right now in Canada would need, especially if they wanted to look into the launch of field of quantum computing, is access to fab. I remember Mr. Dong's questions on Friday about CMOS. This is a great example of the types of capabilities we have to have in Canada. Unfortunately, after the fall of Nortel we lost that capability. We have to rebuild that type of capability, not only for CMOS, but also for quantum. This is the part where we actually could be a leader in the world. We already have the infrastructure in the sense that we have the talent.

Also, I have to point out that the generations who were working at Nortel, who had so many years of experience working in an industrial setting, are close to retirement. This happened a few years ago, so we want to really bank on that. Before these guys go into retirement, we want them to come and help us build a world-leading industrial nanofab for quantum, and CMOS if there's enough budget or if that's within the works. That's the part I would be very focused on and I would very much appreciate help with from government.

The Chair: Thank you, Dr. Yazdi and Mr. Deltell.

We'll now move to Mr. Gaheer for six minutes.

Mr. Iqwinder Gaheer (Mississauga—Malton, Lib.): Thank you, Chair, and thank you to the witnesses for making time for this committee. My first question is for Dr. Laflamme.

Dr. Laflamme, what needs to be done to develop or attract academic researchers in Canada, and how do we retain them? I see stiff competition from top universities in America, the U.K. and Australia, so what can be done?

Dr. Raymond Laflamme: Thank you. It's a very good and important question.

I will give you the answer to how I recruited people for the Institute for Quantum Computing. You need to have a vision of what you want to do, so that the people you are trying to attract know that they are not going to come to a place where they are on their own, doing their little piece of work; they'll be supported by colleagues, students and post-doctoral fellows who can help them achieve the goals they want to.

You also need resources to do this, so if you hire a theoretician, it's relatively easy without too much in the way of resources, but as you've heard from Dr. Yazdi about building a fabrication facility, this doesn't come cheaply. Fortunately, Canada has been leading and helping to provide fabs that are for research, and maybe Dr. Yazdi could have commented on the difference between a fab that you do for research purposes and a fab that you do for production purposes.

For research purposes, you do not have to have a yield that is extremely high; you just want to have devices from time to time that have the right properties. However, if you want to commercialize and sell this, the yield has to be very high, and that's another ball game. Today, for $50 million to $100 million you can have a research fab. If you want to have a fab for commercialization, that goes into the hundreds of millions—if not the billions, certainly if you look at the Intel-type fab—so the cost there is depending on the purpose.

If you want to attract people, you need to have the resources, so having a vision, having a community and having resources are the three most important things. I'll add another one, which is to think outside the box. What I mean by this is, nowadays in the world in which we live, usually, when you hire a person they have a partner who is as smart as they are, so then you have to help them find a job and do various things or establish their family somewhere. That is where people from the committee, like you, can help. It means if you attract somebody from outside, they need a visa; they need support and a certain amount of certainty that they will be able to succeed in what they do.

What I have done in the past is talk to my local MP and ask them to help me to recruit people to come to Canada. I can tell you that 20 years ago the field was a lot easier and much less competitive. It was just the beginning, but today it is incredibly competitive. I see my three colleagues here, and they know what I mean about when you try to attract a really good person to come and join. The success is not 100%, and this is normal when it is highly competitive, but if we do it and we do it as a team effort, I think we can succeed.

● (1615)

Mr. Iqwinder Gaheer: That's great. Thank you for your answer. I can see very clearly why immigration policy needs to work in conjunction to attract and keep academic talent.

My second question is also for you. What's the benefit of international co-operation on research, and how do we balance security concerns and IP protection with this benefit?

Dr. Raymond Laflamme: This is again an excellent question and a hard one to answer.

On the first part—why we need to have international collaboration—it's that we have very smart people in Canada, but we are only a small proportion of the population of the rest of the world, and there are very smart people around the world. We can take advantage of their knowledge. By adding collaboration, typically on the research side, that helps very much.

Once you start the commercialization, things become a bit more complex, because then you may have both national security issues and also IP protection involved. We know that around the world there are different countries that are very aggressive in learning about what we're doing here in Canada, so we have to be sure that we are alert.

That's another thing I've learned in working in Canada. In fact, in working at a national lab in the U.S., security concerns definitely were something that was kind of up there. When I arrived here in Canada in 2000, there was very little, although I would like to thank people at CSIS and CSEC for their help in ensuring that what we do in Canada is protected in the right way.

Mr. Iqwinder Gaheer: Thank you.

The Chair: Thank you very much.

We'll now move to Mr. Lemire for six minutes.

[*Translation*]

Mr. Sébastien Lemire (Abitibi—Témiscamingue, BQ): Thank you, Mr. Chair.

I thank the witnesses for the important contribution they make to our study. I must say that this has taken me out of my comfort zone for the past few weeks, but it is reassuring to hear their testimony.

Dr. Laflamme, I was surprised to hear you say that we are currently running a marathon. I was under the impression that it was a rather crazy race and that we had to get there first. In the case of a marathon, you think of something that lasts for a long time, and during which you have to save your energy in anticipation of moments when you will have to put in more effort.

Can you tell me more about your vision of the strategy that the Canadian government should adopt?

Dr. Raymond Laflamme: The idea of using the properties of the quantum world to develop technologies is not new. The first ideas were launched in the 1970s. There was a real turning point around the 1980s and around 1994, when an American researcher realized that it was possible to factor numbers that are the product of two prime numbers. This is called “Shor's algorithm.”

This algorithm sounds very abstract, but it is what underlies all the cryptography used today.

The idea of building a quantum computer dates back some 25 to 30 years. That's why I call it a marathon, not a sprint. However, in the last five years, industry has really jumped on board and there have been efforts in several countries to translate quantum information into devices.

So the strategy is associated with a marathon.

I can't tell you when we'll be able to produce quantum computers that will be able to do things that will be interesting to you and your colleagues around the table. My colleagues in industry might be able to make a more accurate prediction than I can, but I would be surprised if it happens within 10 years. It's a long haul.

Mr. Sébastien Lemire: I will ask them about that.

Dr. Laflamme, you also mentioned in your remarks that support in Canada was different from that in the United States.

Are you talking about support through specific government programs and investment opportunities that include research ecosystems?

You also mentioned that there are gaps to be filled. Can you tell us more about that?

What are these gaps in terms of support for our companies and our research centres?

● (1620)

Dr. Raymond Laflamme: Thank you for your excellent question.

In the United States and the United Kingdom, they use a program created by the Defense Advanced Research Projects Agency, or DARPA.

This program enables collaboration between researchers and companies, who can bid together or separately on various projects, often with the government's contribution, to secure funding. It's harder to work this way in Canada. We have programs here that are really limited in that regard, but we could look at improving that.

I have heard that Minister Champagne's mandate letter would float the idea of adopting a DARPA-style model with a distinctly Canadian approach in the coming years. I would support such a project.

Mr. Sébastien Lemire: We often hear that companies in various areas work in isolation.

I'd like to hear your comments on the quantum industry and how we can promote better exchanges and better collaboration between industry and the research community. The government often tends to focus on betting on the right horse instead of focusing on a number of things, particularly in the quantum industry, and then seeing which one stands out. Your reference to a marathon may apply again in this case.

How do you see the quantum industry growing?

Dr. Raymond Laflamme: Until seven or eight years ago, very few Canadians were going into the quantum industry. In the last five or seven years, there has been a dramatic change, and the industry is growing, which is a good sign. The question I have and that I don't have an answer for—it will take a team effort—is how do we give all these start-ups the means they need to grow and become full-fledged companies? That's where the national quantum strategy needs to come in.

This field of expertise is still in its infancy, and there is much to experiment with. There is no guarantee that we will find the best approach the first time around, but even if we make mistakes along the way, recognizing them will lead us to correct the situation and move forward. That's the idea behind quantum error correction, which Mr. Janik talked about a little bit, but with the commercial side rather than the quantum information side.

I think quantum ecosystems are a way of supporting both academia and businesses. We must ensure that government research laboratories, as well as Defence Research and Development Canada and Natural Resources Canada, are able to join these ecosystems. It would provide a mix of ingredients for the emergence of companies that will form the Canadian quantum industry of the future.

Mr. Sébastien Lemire: Thank you very much.

The Chair: Thank you, Dr. Laflamme.

Mr. Masse, you have the floor for six minutes.

[*English*]

Mr. Brian Masse (Windsor West, NDP): Thank you, Mr. Chair.

I'll try to get some of our other guests involved in the conversation. I'll start with Mr. Yazdi, and then I'll invite any others to talk.

The question I have is, once you start to scale up or get involved as a company and grow, what are the key elements that you need?

A concern I've seen in some of our other industries is that you get gobbled up once you're successful. I don't know whether that's the situation for quantum computing. I've seen that in tool and die mould-making and other types of businesses.

I'm curious about that element and whether or not there are enough supports for growing, and then getting to the next level in the private sector.

● (1625)

Dr. Alireza Yazdi: Thanks for the excellent question.

As a company grows, especially a deep tech company like ours, access to two things becomes very critical. One is funding and the other is talent. I believe we could do better on both counts here in Canada.

With respect to talent, as Professor Laflamme mentioned, there is a very competitive market out there. We are competing against the likes of Google and IBM and the salaries and job conditions they can offer. That's very hard. It doesn't help that our visa system doesn't support bringing in talent from outside.

Right now, it's very hard to hire an experimental quantum physicist. You have to go through a lot of bureaucracy to get an LMIA certificate. It would be much easier for me to hire a cook here in Montreal than to hire an experimental physicist. That has to change.

Mr. Brian Masse: I'll let our other guests intervene, if they're interested, but first, I want to make sure I have it right.

I did some work with the video game industry, and they had a hard time with immigration. They needed to hire a director, so to speak, to create the video game. We had a lot of talent for a lot of the components, but they had to bring in a director. It was turned down for years seeing there was not a Canadian interest in that, which was wrong, because we couldn't develop the rest of the infrastructure. We didn't have the captain, so to speak, or the director to put the pieces together.

Is it similar to that for where we are? Do we need that exceptional talent or skill set that's very unique and hard to get to build the other components and train people to get into those positions eventually?

Dr. Alireza Yazdi: That's exactly the case. I would encourage the government to create exceptions and new lines in the immigration system to allow us to hire people who have expertise in quantum computing, in particular. Of course, the access to funding is very important.

Yes, we fortunately now have the BDC deep tech venture fund. I think the two other companies here have benefited from that investment, but last time I heard, they're preallocated on their budget with respect to investing in quantum hardware companies, so that already closes the door for many other interesting start-ups that are trying to get into the industry.

These are the two things that come to mind. I believe the other guests also have some points to make.

Mr. Brian Masse: If there are any other guests, please....

Mr. Janik.

Mr. Rafal Janik: Absolutely, I would echo what has already been said.

On the talent side, we've experienced a bit of a different situation. We've been incredibly lucky that we've been able to bring over 60% of our workforce through programs like the global talent stream. In fact, between the quality of life in Canada and the relatively open immigration policy, we've been able to out-compete a lot of our peers in the United States for talent.

On the funding side, I want to add a comment about the scale of funding that we're talking about. To date, we've been incredibly lucky and we've been able to raise over $175 million Canadian for the goal of building a fault-tolerant universal quantum computer. That's probably about 20% of what is needed to deliver this truly transformative machine. There becomes a really big security and strategic question. There was a question earlier around how we keep this IP within Canada. Probably one of the biggest threats is that once companies get large enough and successful enough, they'll need that outside equity, that outside money, in order to come in and bring them over the goal line.

I'm not sure what the solution is, but definitely one problem we need to solve is how we move past the early stages, the academic side, to the true commercialization side, to be able to reap the benefits of all the investment that has already been put into quantum technologies.

Mr. Brian Masse: Are there any other guests...? I'm not sure if I have any time left.

Dr. Philippe St-Jean: One point to your second question about the end game for quantum computing companies in Canada is that we've seen a bit of consolidation recently, but mostly those are companies that were doing a single component of the whole system, like control systems, for instance, and were acquired by another company. We've also seen some consolidation of quantum software companies with quantum hardware companies.

It's not so much companies being gobbled up, per se, like someone building a quantum computer and being acquired. That's not something we've seen so far. It doesn't look like it's going to be happening any time soon. To Mr. Janik's point, this will be a question of whether we have the capacity to fully fund the full story, ultimately.

● (1630)

The Chair: Thank you very much.

We'll move to MP Gray for five minutes.

Mrs. Tracy Gray (Kelowna—Lake Country, CPC): Thank you, Mr. Chair, and thank you to all of the witnesses for being here. My questions are for Dr. Laflamme.

There is a patent box policy presently in place in Quebec. Do you think implementing a patent box policy around quantum computing would be beneficial to keep investment here in Canada and protect IP?

Dr. Raymond Laflamme: I am not sure what a patent box IP policy is, living in Waterloo, Ontario. I'll point out that the University of Waterloo has a very interesting IP policy, which is that the researcher owns the IP, so in my—

Mrs. Tracy Gray: If I could just interject, it has to do with intellectual property assets. Looking at quantum computing, how would it perhaps fit in within that category?

Dr. Raymond Laflamme: Who would own that patent box?

Mrs. Tracy Gray: Maybe we'll move on and we'll send you a note separately. It has to do with the actual assets of a company and looking at how quantum computing might fit into that.

I'll move on, because I have limited time here.

This is another question I wanted to ask you. Concerns have been reported that the emergence of quantum computing will require a need to update standards for encryption algorithms to ensure they are secure from any potential attacks, in particular from hacking from nefarious sources by quantum computers.

Would you say this is a concern? How should the federal government approach this to ensure encryptions are secure? Specifically, are there any policies or laws that we might want to be considering around this?

Dr. Raymond Laflamme: It's a very good question. The answer is, yes, the government should be concerned.

When we have the quantum computer, the algorithms we are using for cryptography today will all be broken. We should all remind ourselves that what we are transmitting around the world today through the Internet will be broken once we have a quantum computer.

Fortunately—and it's not because I want my colleagues to slow down on their goal of building a quantum computer—I do not believe that this will happen until at least 10 to 20 years from now.

The federal government should think about moving from the algorithms they are using right now to new algorithms that are quantum-resistant. There are efforts to go in this direction at both CSEC and CSIS, and in the U.S., at the National Institute of Standards and Technology.

Mrs. Tracy Gray: That's great. Thank you.

I understand that in budget 2021 the government intended to develop a national quantum strategy and held consultations.

Were you able to participate in those consultations or round tables?

Dr. Raymond Laflamme: Although I was not in the consultations themselves, I was part of the executive committee that made a proposal for budget 2021. I was part of a proposal that was put together, asking the federal government to fund a national strategy. I definitely had some input in that document.

Mrs. Tracy Gray: Thank you. Were there any potential pitfalls that the federal government should be aware of when developing a quantum strategy?

Just to tag onto that, are there any lessons or policies that other countries are using around quantum computing that Canada should pay attention to and look at replicating here?

Dr. Raymond Laflamme: Canada should have its own strategy. It should not follow what other people are doing. If we follow what other people are doing—let's say, the United States—they have a lot more resources than we do. We have to find our own niche. We heard comments a bit earlier on making choices, deciding what is really important for Canadians and following that path.

However, we definitely have some lessons. Bringing people together is something that other countries have been doing. Trying to think about quantum information science not as a bunch of different boxes next to each other, but as a whole, is really important. This comes back to the theme of having these quantum ecosystems, which I mentioned a bit earlier.

● (1635)

Mrs. Tracy Gray: Thank you. I have one more quick question here. I wanted to ask you about privacy.

How would the emergence and adoption of quantum technology affect Canadians' privacy and the protection of personal data? What privacy laws do you think we should be updating and looking at now?

Dr. Raymond Laflamme: There are two parts to privacy. One is whether we communicate privately with each other. Then, also, the codes that are used to secure your bank accounts are the same ones that are used for private communication. These encryption methods will have to be upgraded.

Once we have this, for the rest there's not much difference from a privacy point of view from what you have without quantum computers. Whether you have a piece of information that comes from a quantum computer or from a classical computer, it's just information.

The Chair: Thank you very much.

We'll go now to MP Lapointe for five minutes.

[*Translation*]

Ms. Viviane Lapointe (Sudbury, Lib.): Thank you, Mr. Chair.

[*English*]

I'd like to continue with the line of questioning started by my colleague, Mr. Gaheer. I think these are key areas where government and policy can actually be helpful.

My first question is for Dr. Yazdi.

You have both research and business knowledge in the quantum field. On your website, you made an interesting statement that you recognized that “the newly emerging field of quantum computing lacked tools to engineer large scale systems”. Because of that lack of tools, you had to be very innovative and draw from your expertise in high-performance computing to develop those tools.

In terms of economic development and supply chain for hardware, what challenges do you see? What can government policy do to help?

Dr. Alireza Yazdi: Thank you very much for the excellent question.

I'll start with the second part of the question, which is the supply chain, because supply chain is what keeps me awake at night, and I mean it in a literal manner. These days, our [*Inaudible—Editor*] chips are 52 weeks back-ordered, so this is very serious.

Right now in the United States they're looking very hard at the supply chain of quantum computing. This was one of the reasons that Anyon, back in 2016, decided that they were going to make every component of a superconducting quantum computer internally. For example, there are only two companies that are making commercial-grade cryogenics systems. One is in Finland and the other one is in the UK. They can easily be bought by other competitors, and that's very detrimental to the future of our industry.

What I recommend that the government do is the same exercise that our partners in the U.S. are doing. First, choose what priority technologies you want to invest in, try to secure them, and bring them to Canada. What the pandemic showed us is that even having masks and PPEs could be strategic; in times of need, we couldn't get them, even from our friends.

I would look at the supply chain very carefully.

I would highly recommend that we consider other chip fabrication as the Achilles heel of this, both on the classical side, on CMOS, and also on the quantum side, which I think could be our niche in the global market. Right now, we are as competitive as any other country in building superconducting...or other types of quantum devices. This is the part I would recommend that the government take a very good look at and think about making a priority.

Ms. Viviane Lapointe: I have a follow-up question.

Clearly, establishing downstream ecosystem opportunities to support a quantum sector is necessary. What types of supply chain supports are needed by your sector?

Dr. Alireza Yazdi: In our industry, one is the cryogenics system, which we make ourselves. There is electronics—controlled electronics and microwave electronics. Right now the biggest supply chain for that comes from the United States. It then comes down to nanofabrication. Right now, we're using a shared facility at Waterloo.

Again, the Achilles heel of all this goes back right now to electronics and building what we call field programmable gate arrays, FPGAs, and ASIC chips. This is not only in Canada; the whole world is dependent on Taiwan, to a great extent, especially the foundries at TSMC. I believe it is a geopolitical Achilles heel, because if China decides to invade Taiwan tomorrow, this could melt down a lot of economic sectors across the world.

This is also something we should really think about in a bigger strategic and economic context than just quantum.

● (1640)

Ms. Viviane Lapointe: Thank you.

Quickly, Mr. Fursman, in terms of having qualified individuals at all levels of quantum sector development in Canada, what's the number one thing you suggest that Canada can do, not only to attract but to develop the talent here as well?

Dr. Alireza Yazdi: I'm sorry. For whom was the question?

Ms. Viviane Lapointe: What do you suggest we do to attract and develop the talent here in Canada?

Dr. Alireza Yazdi: I assume I'm going to answer that.

One thing I highly recommend is that we look into partnering universities and industries to make sure the training they're receiving in academia matches the needs in industry.

Unfortunately, this is one of the areas we have not been great at, especially in basic science—quantum is actually emerging from that. Quite often we see people graduating with Ph.D.s, doing research on topics that are not exactly relevant to what we want, but that's what we have to work with. Then, there is a lot of training on the job.

This could be another important point in our national strategy, hopefully, to find ways to make sure the universities have an insight into what the industry needs in the short and long term.

Ms. Viviane Lapointe: Thank you.

[*Translation*]

The Chair: Thank you, Dr. Yazdi.

Mr. Lemire, you have the floor for two and a half minutes.

Mr. Sébastien Lemire: Thank you, Mr. Chair.

Dr. St-Jean, thank you for your testimony.

You said that you wanted to end your remarks on an optimistic note, which made me react a little, because that implies that there are not always optimistic moments in the industry. I would like to hear your comments on that.

You also said that you were always looking for short-term income and that you wanted to receive enough money. You also talked about the delays in the approval process of projects, which sometimes make them irrelevant. So there's a real problem with the speed of response and support for the industry.

How could support be translated, for example through programs? Concretely, how can we help you in terms of production, when you're ready to move to that stage?

Dr. Philippe St-Jean: A way should be found to allocate funds to research and development related to quantum technologies. The current programs have their constraints, which is normal. Since these are public funds, guidelines must be set for these subsidies.

For example, funding could be allocated to an organization run by specialists, by people who already have expertise and who are able to quickly assess the files and ensure that the amounts requested will support the right initiatives.

In addition, there was discussion earlier about DARPA in the United States. Massive efforts are being made by the Americans. One of the things DARPA does is provide funding opportunities, and Canadian companies can apply. If they meet the requirements and if they get funding from DARPA, it would be interesting to have some sort of matching on the Canadian side. It would save the government and those companies time, because the project would have already been approved by a serious agency. We are small companies, and having to submit a project twice, based on criteria that are not quite the same, takes a lot of time.

Mr. Sébastien Lemire: You're looking for error-tolerant technology.

Should we have the same philosophy when it comes to funding? In other words, should there be better venture capital?

Dr. Philippe St-Jean: You raise a good point.

We talked earlier about the new investment fund offered by the Business Development Bank of Canada to support what companies call “deep tech companies”. We have benefited as a start-up in this area. It's very interesting, but there is indeed a gap in Canada.

It was very important for us to join forces with this partner. These are people who think about long-term solutions. Typically, a technology investment fund has a horizon of about 10 or 12 years. In the case of quantum technologies, you have to think about longer-term solutions. This is what we would like to see emerging in Canada and, above all, at all levels in terms of funding.

For pre-start-up and start-up companies, finding small-scale funding isn't easy, but it's possible. The subsequent steps create greater challenges. Xanadu had done it, and we're very proud of them. This is a very good example of what can be done in Canada. This company has obviously received help from foreign investors. That's also the case for us, because we've had a European investor since day one.

Some form of support needs to be provided at all stages. It's important to think about solutions now, because these companies are currently growing.

● (1645)

Mr. Sébastien Lemire: Thank you.

The Chair: Thank you, Dr. St-Jean.

I doubled Mr. Lemire's time because the question was interesting. The answer was equally interesting.

Mr. Masse now has the floor for two and a half minutes.

[*English*]

Mr. Brian Masse: Thank you, Mr. Chair. That was a good investment. It was a good exchange.

Mr. Laflamme, you might be able to answer this question the best: With regard to international students, what do we do with regard to retaining them?

I think our country hasn't done a great job. I represent the University of Windsor and St. Clair College, where we have a lot of international students and there's a big debate about their costs and what they incur with the debts they have, paying higher tuition fees. There's also a debate about how we actually can bring in as Canadian citizens those individuals who want to stay. There has been a lot of success, because they have a lot of invested community connections at that point in their education.

I wonder whether we're seeing that now in quantum computing, or whether it's too early. Has it been happening? What's going on with international students?

There's losing talent, but there's also bringing in talent.

Dr. Raymond Laflamme: Absolutely. I would say that, looking at my 20 years of being back in Canada, and looking at the students who are coming from the outside to Canada, things have been incredibly impressive. Interestingly—and maybe this is only one point of data among many—very few people from the United States would apply to do a Ph.D. at Waterloo in quantum information in 2002-03. Now, we're seeing a much larger number of 10% to 20% in some years.

We have definitely made a lot of progress, and I think that relates to the strength of quantum computing and the reputation that we built during that time.

To keep them around, I think my colleagues in the industry might want to put a little more worth on this. At the university, they come and they do a master's degree, a Ph.D. and sometimes a post-doctoral study, and then they have to move on. We don't keep them after that, and it's good for them to go and move [*Technical difficulty—Editor*] one location to the other.

In the start-up scene, certainly around Waterloo, I've seen many of the students worry about returning. I do not remember the number of years you have to be in Canada as a student to become a permanent resident, but I've seen many of them try to do this. This process is often cumbersome and hard, and maybe there are better ways to make it more fluid, so that colleagues in industry can hire these students more easily and get a better talent pool to develop quantum technology.

Mr. Brian Masse: I think I'm out of time, so I'll give the second part of that to the other panellists in my final round.

Thank you, Mr. Chair.

[*Translation*]

The Chair: Thank you, Mr. Masse.

[*English*]

I'll now turn to Mr. Kram for five minutes.

Mr. Michael Kram (Regina—Wascana, CPC): Thank you, Mr. Chair.

I would like to come back to Professor Laflamme and follow up on some of the questions that my colleague Ms. Gray was asking.

Professor Laflamme, did I hear you correctly that once quantum computing technology becomes widespread, all of our current Internet encryption and decryption will be obsolete?

Dr. Raymond Laflamme: Yes. The algorithm behind the encryption that you are using to log in to your bank is something that a quantum computer will be able to break easily. Therefore, the relationship between quantum computing and national security is obvious on that point.

Mr. Michael Kram: Is it correct that the same algorithms that I use for my bank are also used by the military?

Dr. Raymond Laflamme: Most of them are. It is possible that there are algorithms that remain safe against quantum computers, but these are more complex algorithms and they are used very little.

The military in Canada and the U.S., the west, and even China and Russia know that this is coming. There will be a change in cryptography, and it is really important that this is something that the Canadian government follows, so that people at CSE are in the know about what is happening.

● (1650)

Mr. Michael Kram: I believe I also heard you say that Canada will have, for lack of a better word, "perfected" quantum computing technology in the next 10 to 20 years.

Dr. Raymond Laflamme: I think I will leave it to my colleagues from the industry to really say this.

Maybe I should put it in a slightly different way. It would be rather surprising for us to have a quantum computer that is fault-tolerant within, roughly, the next 10 years. However, I'll leave the words to my colleagues, Drs. Yazdi and St-Jean and Mr. Janik, if they want to make some predictions. There's still a crystal ball prediction in all of this.

As we look at the progress around the world and in Canada, that would be the best guess I would make right now.

Mr. Michael Kram: Do you have a best guess as to how far away the Russians and North Koreans are from developing these technologies?

Dr. Raymond Laflamme: It's very hard to make a guess. I would be able to make comparisons only from an academic point of view.

It would be surprising if North Korea developed a quantum computer. They do not seem to have that type of expertise and technology. The Russians have a strong group around Moscow, but they were very late to the game, so I would fear the Chinese more than the Russians at present.

Mr. Michael Kram: You also mentioned that once you came back to Canada, you had to work with CSIS and CSEC to increase security measures around our quantum computing research. Can you expand a bit as to whether those security measures are adequate, in your opinion?

Dr. Raymond Laflamme: Any security measures can be improved, but the work they have been doing has been incredibly good at ensuring that what has been discovered in Canada remains here or is owned by Canadians. I thank them profusely for their help in pointing out weaknesses that were around.

Mr. Michael Kram: Okay. That's very good. I'd like to switch over to Dr. Yazdi next.

Dr. Yazdi, you successfully delivered a quantum computer to the Department of National Defence last year. Is that correct?

Dr. Alireza Yazdi: The mission is complete and we're in the process of onboarding some of the researchers.

Mr. Michael Kram: Would I be correct in assuming that cryptology research is the primary purpose of this computer?

Dr. Alireza Yazdi: I cannot comment about it, because—

Mr. Michael Kram: I thought you might say that. I have to say, that's a very good answer.

What can the government do to improve the state of quantum computing at the Department of National Defence?

Dr. Alireza Yazdi: For the Department of National Defence, of course, given its mission, I think quantum computing would be disruptive to its business. Professor Laflamme mentioned the potential challenge that a quantum computer might pose in terms of encryption, and I echo his assessment.

I think a machine that can break encryption is a few years away, still at least a decade away. That doesn't mean a quantum computer's usefulness is so far away. We could have smaller-scale machines doing some other stuff that could be relevant to the Department of National Defence, but decryption is probably a bit of a longer time horizon here.

That said, the question is what type of post-quantum encryption algorithms we're going to adopt, because some of the information being exchanged right now throughout the government network probably has a shelf life of more than 10 to 20 years. You want to essentially secure them right now, because they could be collected by an adversary and sit in their storage for decryption whenever the quantum computer comes around.

Therefore, the sooner we can adopt the right technology to improve our encryption infrastructure, the better it is for the security of our country. Of course, access to hardware could, for example, be used to test some of these algorithms.

These are the areas that I think could be relevant to the mission of the Department of National Defence.

● (1655)

Mr. Michael Kram: Thank you.

The Chair: Thank you, Mr. Kram.

I'll turn now to Mr. Erskine-Smith for five minutes.

Mr. Nathaniel Erskine-Smith (Beaches—East York, Lib.): Thanks, Joël. My question is for all our witnesses. I'll start with Mr. Laflamme.

The government's consultation around a national quantum strategy is the "What We Heard" report that we have in our hands so far. As part of that, in relation to commercialization, the report states:

> When addressing support for quantum companies, there was consensus that government should remain inclusive and not pick winners at this time, as quantum is a developing sector. At some point, Canada will need to make a strategic decision whether to support a few large players or projects, or many small ones.

I'm looking for comment on the strategic decision that Canada will have to make at some point, according to the "What We Heard" report.

I'll start with Mr. Laflamme, and then Mr. Janik.

Dr. Raymond Laflamme: Again, it's a hard question, because what you're really asking is to predict when we will know the technologies are ripe enough that we can made that decision.

I would hope that by the end of the period of this national strategy and its funding, which is seven years, we would know which horses are much ahead of the others.

Mr. Nathaniel Erskine-Smith: I take from that answer, though, that the government has to make a decision before the seven years are up, because money is rolling. Therefore, at this point you're saying many small ones, and at the end of the seven years maybe a few large ones.

Dr. Raymond Laflamme: Yes.

Mr. Nathaniel Erskine-Smith: Mr. Janik, and then we'll go to Mr. St-Jean and Mr. Yazdi.

Mr. Rafal Janik: Maybe one difficulty that's really present here is that there is not one type of approach to quantum computing. We have three leading ones in photonics, trapped ions and superconducting. Two of them are represented here today. Really, there are probably another five that are getting started in labs around the world right now.

I would say the signal I would look for is, instead of focusing on raw qubit numbers today.... Any company you ask here and any one around the world, ranges from 10 to 150-200 qubits, but really we're talking about a machine with millions of qubits. There's a really big scaling issue from the technological side, to go from 10 to 1,000 to a million.

I would say, when you see the first signs of true fault tolerance coming from any one of these companies, and Dr. Laflamme is able to sit here and say they have demonstrated quantum error correction and fault tolerance, that's really the time to start getting excited that there's somebody who can deliver on this really big promise.

The other piece there is modularity. When we talk about these systems today, we're talking about individual chips with tens to hundreds of qubits. When you're talking about a machine that has a million qubits, this is a data centre. To give you an idea of the manufacturing scale, the prediction is that the number of chips you will need for a million-qubit device is probably similar to all the number of chips that are produced today in a year for the telecommunications industry, from at least the photonic side. This is really a big, 25,000-square-foot data centre that we're talking about. This is not a small device, so scalability, modularity and demonstration of error correction are really the big things.

One final thing—

Mr. Nathaniel Erskine-Smith: In the interest of time we'll have Mr. St-Jean and Mr. Yazdi, and then we'll come back to you, Mr. Janik, if I have a bit more time then.

Dr. Philippe St-Jean: I'd just like to say, your question is about funding many small opportunities. The question is, how many exactly?

Mr. Nathaniel Erskine-Smith: Yes, what the government is faced with, in its consultation at least, is whether to spread thin and make many small bets, or make a small number of large bets?

Dr. Philippe St-Jean: I would say there should not be too many criteria, obviously. Anyway, you won't have the expertise necessary to do that. It should really be focused around.... We have the good fortune to have centres of excellence in Canada, so this limits in a sense the number of possible companies that can emerge. I would centre the decision mostly around that, and then I agree with Mr. Janik on how it's going to evolve over the—

Mr. Nathaniel Erskine-Smith: Thanks.

Mr. Yazdi, do you have anything to add?

Dr. Alireza Yazdi: I think the decision should be a funnel-type decision-making process. You start with a few bets—not too many, but not too few either. Then you let the companies make progress, and the winners or leads would come out after the seven-year process. That's when the country has to make a decision.

I just want to also emphasize, if you look at China, given its resources and given its manpower, whatever you call it, it did not choose the way we're doing stuff. It's like a type of Manhattan Project, or a Bletchley Park type of project—all the resources are starting to be consolidated behind one or two groups, and they're making very rapid strides. They're making very rapid gains. Five or six years ago, when we started, there was essentially nothing in experimental superconducting qubits in China, and now they have a 65-qubit chip bigger than Google's.

This is a very important question, and I think it's subject to further discussion.

● (1700)

Mr. Nathaniel Erskine-Smith: Thanks very much.

The Chair: Thank you, Nate.

We'll go now to Monsieur Généreux for five minutes.

[*Translation*]

Mr. Bernard Généreux (Montmagny—L'Islet—Kamouraska—Rivière-du-Loup, CPC): Thank you, Mr. Chair.

I'd like to thank the witnesses for their testimony.

I'd like to delve further into the issue of funding.

Mr. Janik, you said that you raised over $170 million and that this represented about 20% of the amount you needed to build a quantum computer.

Does that mean that your product could be worth $1 billion one day?

[*English*]

Mr. Rafal Janik: The total adjustable market for quantum computing right now is estimated at $65 billion when we deliver a fault-tolerant quantum computer. I'd say that is the pessimistic estimate, compared to some of the other ones that have been out there.

I can't stress enough that when fault-tolerant quantum computing gets here, there will not be an industry that will not be disrupted by this. Every single thing that we know will change. It will take time for the applications to catch up, but this will be as revolutionary as digital computing was at its advent in the 1950s. The market is definitely there.

We've stood up quantum computers today. We've had six different quantum computers online since 2019, with users from large national labs in Canada and the U.S., and from corporations. Those are all kind of at that pre-fault tolerance, pre-economic value stage.

The R and D part is not the part that will take a billion dollars. We believe that we're well funded to take us well into building that fault-tolerant module, to being able to demonstrate and de-risk all the technology and all the science required to build a fault-tolerant quantum computer.

Once you need to build the machine that builds the machine, and once you need to switch modes from R and D into true manufacturing, that is a very large investment. You need to go to the largest production facilities in the world—the TSMCs, the GlobalFoundries, the Intels—and get their most advanced production lines producing these chips at scale and then integrating them. It's a very big task.

[*Translation*]

Mr. Bernard Généreux: We hope that the national quantum strategy will be implemented soon.

Dr. Laflamme, research and development is normally carried out at universities, such as the University of Waterloo, the Université de Sherbrooke and Université Laval, in Quebec City.

Shouldn't government money go to universities? That's where the research and training is done. The government could then, in co-operation with the National Research Council of Canada, or NRC, commercialize or allow the product to be commercialized, after listening to the solutions proposed by the Centres collégiaux de transfert de technologie au Québec, or CCTT.

We're talking today about three private entrepreneurs who are also looking for federal funding. If we had an amount to distribute, what percentage should go to universities for research, and what percentage should go to private companies?

Dr. Raymond Laflamme: That's a very good question.

Funds should be distributed in such a way that there is a positive interaction between universities and industry. Making a quantum computer is incredibly complex. Universities can create really simple prototypes and lay out principles of operation, but it's the industry that integrates all this to build a quantum computer. The reason is simple: students spend three, four, or five years in university doing their master's or doctoral studies, but it takes even longer to build a quantum computer, and that requires follow-up.

The national quantum strategy should really include a partnership between universities and industry, rather than treating the two separately.

The idea behind the quantum ecosystem that I've talked about several times today is to bring universities and industry together so that they can benefit from each other. The distribution of funding between industry and academia should depend on the project and its size. The allocation won't be the same for a research project as for an integration project or a quantum computer manufacturing project. If you're asking me for a number—

● (1705)

The Chair: Unfortunately, your time is up, Dr. Laflamme.

Mr. Bernard Généreux: Do you think there will ever be a battery charger that can recharge a battery in nine seconds using a quantum computer?

The Chair: We could discuss this again in a future study, Mr. Généreux.

Mr. Dong, you now have the floor for five minutes.

[*English*]

Mr. Han Dong (Don Valley North, Lib.): Thank you very much, Chair, and I want to thank all the witnesses for coming today.

I took note of what Dr. Laflamme said, that Canada never missed an opportunity to miss an opportunity. I will memorize this as a reminder.

All my colleagues asked great questions, both today and the day before. I think now I'm more confused than before from the testimony. It's full of contradictions. I think, as with any new technology, that is actually a good thing. That will help the committee to come up with a study or recommendations that will be more comprehensive. I just feel for the analysts, who will be having trouble to put together a report.

Speaking of contradictions, I hear the explanation that it's not ready, yet it is ready. When I asked a question on Friday about the processor chip—we need to have a manufacturing capacity—I was also told that the computer processing hardware may be very different with quantum computing, so it's really hard to predict this. There is the contradiction there.

I will list a whole bunch of them, and you can explain it to me later.

In my head there is the supply chain aspect, including critical minerals that will provide the raw materials that are necessary for mass production, and then there is the manufacturing sector. To what stage should they be preparing for this disruptive technology? Then there's the research aspect of it, and we heard the testimony on this. The one contradiction was the receding globalization, but I also heard that it's necessary for Canadian researchers to work collaboratively with smart people around the world.

To me, these three main stages are full of contradictions.

I want to start with Mr. Laflamme, if you have any comment on this, and then go to Mr. Janik, Dr. Yazdi and Dr. St-Jean for comments.

Dr. Raymond Laflamme: Mr. Dong, it is a really good question, and you're absolutely right. There are contradictory forces or directions that come in. I could make a little joke that when you come into the quantum world, things appear very different from what you are expecting, and you can probably see a little of this coming through here.

Let's come back to interaction, internationally or not. [*Technical Difficulty—Editor*] pure research, fundamental research into this phenomenon. Can we harness this phenomenon for a practical purpose? If we just want to demonstrate proof of principle that this thing works, we publish our results in journals. That's how academics get rewards or fame; they publish a paper that makes a breakthrough and does something.

That piece of the research has to be international. You have to collaborate with the rest of the world. You gain something from the rest of the world, and the rest of the world gains something from you. In that sense, that piece has no kind of direction yet. This is really good.

Once you have an idea of how to build a device for practical things, suddenly you have to make a transition. Sometimes this happens in universities. A researcher at a university says, “Ah, we can patent this.” The researchers at the university have to be very agile in realizing that sometimes there are things that are purely fundamental, and their reward is fame.

Let's suppose they get a Nobel Prize for the work they have done. Suddenly, they realize that this thing becomes practical. Then they have to be quiet about it. They have to have a team, and they have to tell their team at some point that there are things they are to be very quiet about.

With my students, for example, there are things that I will not discuss outside of my group meeting, and the students know that certain things are not to be discussed until we do certain things with them, so there is this transition.

When you come to industry, suddenly you have a certain IP that protects what you want to have. Even that, with a company.... Again, Dr. Yazdi mentioned the chain of equipment that you need, certain pieces that you need. You don't build everything totally from scratch. He mentioned FPGAs. Suddenly you rely on the global trades around the world to provide some of these pieces, so you cannot be totally isolated. In fact, you should not be totally isolated because suddenly you will realize there are better ones than the one you knew about, and you learn about this from your colleagues around the world. Suddenly there is somebody who makes a little chip somewhere, let's say in Austria, in France, in the U.S. or in Taiwan, that helps you make a leap and control what you have in your lab better.

● (1710)

Mr. Han Dong: Thank you.

I want to make sure others have a little time—

The Chair: I'm afraid that's not going to be possible, Mr. Dong.

Mr. Han Dong: Okay.

Dr. Raymond Laflamme: I apologize.

The Chair: We're already over time, but it was a very interesting answer. Thank you, Mr. Laflamme, for that.

We'll move to Mr. Lemire for two and a half minutes.

[*Translation*]

Mr. Sébastien Lemire: Thank you, Mr. Chair.

Dr. St-Jean, what I find intriguing about quantum computing is the logic involved in operating this type of computer. I'm thinking in particular of the electricity consumption it may require.

Are there clusters of servers that consume endless data and energy, or is it a computer that constantly regenerates its own energy?

Are the energy needs of a quantum computer greater than those of traditional computers?

Dr. Philippe St-Jean: We don't expect to have those needs. However, my answer needs to be somewhat adjusted based on the comments made earlier by Mr. Janik.

There are many ways to build a quantum computer, and the technology used can vary. For our part, we use superconducting circuits. There are some advantages to using them, because no heat is generated by the processor itself.

I should add that this technique presupposes the existence of computer controls that, for the moment at least, still function in a conventional way, if I can put it that way.

It's difficult to predict exactly how this technology will be deployed in the future, but we don't think it's going to be an issue in terms of energy consumption. In fact, we believe that these processors will consume less energy than the current systems, taking into account the large number of calculations they will be able to make.

Mr. Sébastien Lemire: Quebec has a large hydroelectric capacity, which is managed by its Crown corporation, Hydro-Québec. Does that not give it an advantage in that area? I imagine that ties are being forged with the Crown corporation. In an article for *Le Devoir*, Alain McKenna highlighted the fact that quantum computing could be a huge solution for Hydro-Québec.

Have you established ties with the Crown corporation?

Does Quebec have a strategic advantage in terms of hosting research centres, precisely because energy is affordable and accessible in large quantities?

Dr. Philippe St-Jean: I don't think that's a critical point. I know what you're referring to in terms of Hydro-Québec. It's a very interesting research project, which is more focused on value for money internally, as I understand it.

● (1715)

Mr. Sébastien Lemire: [*Technical difficulty—Editor*] and I found it interesting to think about the role that energy consumption could play in quantum computing.

Dr. Philippe St-Jean: As far as energy is concerned, I don't think it will be a critical point for quantum computing. Some people would object if I said it was.

Mr. Sébastien Lemire: Thank you very much.

The Chair: Thank you, Mr. Lemire and Dr. St-Jean.

Mr. Masse, you have the floor for two and a half minutes.

[*English*]

Mr. Brian Masse: Thank you, Mr. Chair.

I want to return to the question of the private sector. With regard to young students in Canada who finish their education, are you getting many of those people coming forth?

In my office alone, I've had immigration staff. In 2002, I brought somebody in one day a week. They're up to four days a week right now, because of the processing. The government has a real problem, because it only allows five cases a day and I have 2,000, 3,000, or 4,000 cases.

I wonder whether or not you're getting young people who are foreign students and having issues in keeping them.

Maybe Mr. Janik can go first, and then we'll go from there.

Mr. Rafal Janik: We've been incredibly lucky in being able to track young talent, ranging all the way down to high school, actually. We had an intern who started with us a few years ago and is now pursuing their undergraduate degree. They have continued to work with us throughout the summers. I'd say access to high-quality talent at all levels has been great for us.

It depends on their roles. One thing we're really lucky with is the fact that we also have this big software layer that we're working on. It has a big community focus as well, so we're able to engage people earlier in developing content for universities and high schools in roles that are much more applicable. Some of the roles on our hardware side, unfortunately, require 10 years of experience in labs like Waterloo to make sure they're able to move the needle forward for us.

I'd say we're not hiring nearly as many young people and catching them as early as we would like, but most of that issue is based on the skill sets they're coming with.

Mr. Brian Masse: That's great—

Mr. Rafal Janik: Maybe one other thing is that we leverage a few different programs. The overhead of programs like Mitacs is often more than the value they drive to us. We've been working hard with those organizations to reduce that, but very often we prefer to hire directly, as opposed to partaking in certain programs.

Mr. Brian Masse: That's great.

Dr. Philippe St-Jean: Perhaps I'll offer a similar comment on our side. We have interns working at Nord Quantique at the undergraduate level, for instance, and this is a fantastic way to get them to also start acquiring knowledge as they grow.

We also have collaboration with master's and Ph.D. students in joint projects, and we even have part-time employees who are finishing their Ph.D.s as well, so this is also a great way to do that.

Dr. Alireza Yazdi: This is an excellent question and very close to my heart. I am a first-generation immigrant; I came here to Canada to do my graduate work, and I stayed, so I relate to a lot of those young folks you talk about.

My comment is that in recent years, it's becoming a bit hard for people to stay in Canada, simply because, once they graduate, they still don't have any real status, any permanent status, in Canada. They have to apply for postgraduate work permits for only two years, and quite often the immigration process takes way more than two years. That's very stressful for many of these young talents, and they prefer to go to places that are either less stressful in terms of immigration or, if it's as stressful, at least the pay scale matches that stress.

I highly recommend that the government reconsider its immigration programs, at least on STEM—the science, technology, engineering and math fields—and make sure that before the student graduates as a Ph.D. or with a master's degree, they have their permanent residency in their pocket. That's the best way to guarantee that the talent we spend NSERC money on stays in Canada.

Mr. Brian Masse: That's the exact testimony I wanted. Hopefully the government will listen.

The Chair: That's a very good point, Mr. Masse. I feel like saying “amen”.

I will turn to Mr. Kram for five minutes.

● (1720)

Mr. Michael Kram: Thank you very much, Mr. Chair.

Professor Laflamme, in addition to your very impressive resumé, I understand you're also a bit of a YouTube star. I watched your YouTube video from late last year, entitled “What are the options for building a large scale quantum computer?”

At the Q and A at the end of this video, you were asked what problem you would like to solve if you were given a quantum computer tomorrow. Your answer was that you would like to focus on the nitrogen fixation problem for making fertilizer. I was wondering if you could explain to the committee what the nitrogen fixation problem is, and how quantum computers can be used to help make fertilizer.

Dr. Raymond Laflamme: That's a very good question and one of the ones that the quantum computer might help us to answer.

What's the nitrogen fixation problem? It's turning what we get out of the ground into fertilizers that are useful, and it turns out that takes about 3% or 4% of the energy budget of the world. If we can improve this by 50%, we can reduce the energy budget of the world by a few per cent, which would make a dramatic impact on things like global warming.

Mr. Michael Kram: Have you shared this idea with Fertilizer Canada or any other stakeholders like that?

Dr. Raymond Laflamme: It is shared with only the quantum community across the world, so definitely a group of people are looking at this as a possibility.

Just in tongue in cheek, I'm waiting for my colleagues Yazdi, St-Jean and Janik to give me a quantum computer so I can go and make this happen.

Mr. Michael Kram: Okay, very good. I would like to just maybe shift gears to Dr. St-Jean.

Dr. St-Jean, in your opening statement, you talked about how the government should act as a first user of quantum computers. I was wondering if you could give some examples of practical applications of quantum computing that the government could use in its operations.

Dr. Philippe St-Jean: There are certainly questions relating to optimization that could be relevant. There's research done in material science as well, and we have had discussions with NRC on the subject.

What else? Pharma is also a field where we expect that we can explore solutions. For now, that will be essentially a toy problem, as we call it, because those systems are not quite scaled yet, as we've mentioned.

Those are the kinds of issues we can start to explore with either NRC or DRDC.

Mr. Michael Kram: Dr. St-Jean, would you include cryptology for national defence purposes in that list as well?

Dr. Philippe St-Jean: Sure. As my colleague mentioned earlier, this is probably a little further down the road. Those kinds of problems would require really full-scale, utility-scale, fault-tolerant quantum computers and at a large scale. We see this as a little further down the road.

In terms of what can be done, however, there are also companies interested especially in those algorithms, so they are doing quantum software or quantum algorithms. Those collaborations make sense. This is not something we focus on, because we are really building out the hardware behind it, but for those partners, that would make sense.

Mr. Michael Kram: Finally, would any of the witnesses care to comment on the applications of quantum computing to blockchain and cryptocurrency?

Dr. Alireza Yazdi: I will pass, if you don't mind.

Mr. Rafal Janik: I can make a comment. It's a question we get surprisingly often.

It's the same algorithm that underlies some portions of the blockchain technology. For Bitcoin, for example, the public key RSA encryption is used within that stack, but just like we know approaches to remedy the encryption problem and it's a matter of implementation, the same thing is present with the impact on blockchain technologies.

We know the solution. It might be a little painful to implement, but it's a matter of actually doing it now as opposed to making new technological breakthroughs to be able to secure those technologies.

Mr. Michael Kram: Okay. Thank you very much.

I see I'm out of time.

● (1725)

[*Translation*]

The Chair: I will use my prerogative as chair to ask a few questions.

Dr. Laflamme, you mentioned, as did other witnesses, that algorithms can be resistant to quantum computers.

For the benefit of the public, can you explain what a quantum computer-resistant algorithm is?

Dr. Raymond Laflamme: Ah, we're finally going to talk a bit about straight science and math.

[*English*]

The people who are doing algorithms classify them as two kinds: the easy one—the one that takes a very small amount of resources—and the hard one, which takes a large amount of resources. Of the two, if I want to be a bit more technical, one takes an exponential amount of resources compared to the other.

The algorithms that are resistant to quantum computers are the ones for which we haven't found a quantum algorithm that turns a hard problem into an easy one. The usual one, which is used for logging into your bank, called the RSA algorithm, is hard for a classical computer; that is, if you want to factor a large number with many bits in it, it takes an exponential number of time in the number of bits of the number that you want to factor.

We have a quantum algorithm that takes that algorithm to an easy one on a quantum computer, but there are other mathematical problems that are used to encrypt information that have remained hard on both a classical and a quantum computer.

[*Translation*]

The Chair: Thank you for your answer.

I'd like to ask you one last question.

Many of you have said that governments around the world are well aware of the risks that quantum computing can pose, primarily for national security. In fact, intelligence agencies are well aware of it.

Is the private sector, such as banks and other industrial institutions, also aware of the potential risk?

The question is for you, Dr. Laflamme, but Mr. Janik, Dr. Yazdi and Dr. St-Jean will also be able to answer afterwards.

Dr. Raymond Laflamme: In Canada, the private sector, including banks, knows the potential of quantum algorithms. The question for banks, for example, is when they will have to change the algorithms they use today for quantum computer-resistant algorithms.

The Chair: I guess it would be a little premature to make such a change now, wouldn't it?

Would it be too expensive?

Dr. Raymond Laflamme: That would be premature, because those algorithms are approved by the Canadian government and the U.S. government through the National Institute of Standards and Technology. The U.S. is involved in the approval process for some of the algorithms. The algorithms used in Canada are closely related to the U.S. algorithms. Once the U.S. approves them, companies will start changing their systems.

The Chair: Thank you very much.

Now I'll give the floor to Mr. Dong, who has one last question. We have only about two or three minutes left.

[*English*]

Mr. Han Dong: Okay, I'll keep it short. Thank you very much, Chair.

I always have this wonder about AI versus quantum computing. I heard that you can't truly realize AI without quantum computing. I want to hear from the experts on this. Speak to process and the nature of the quantum principle.

Is that true? Perhaps you could educate us a little.

Dr. Raymond Laflamme: I'll make a comment and leave it to my colleagues to say more.

I have one little correction. AI is independent of quantum. There's a lot of AI technology on classical computers, which is being used in many different areas.

Then there is the question of whether quantum can really help AI. I think the question has not been resolved yet. There are indications that it could help, but we are not totally sure. There are research programs in Canada. I have one of my research staff looking at some of these issues right now, and other places around Canada will do that—

● (1730)

Mr. Han Dong: I'm just going to ask something.

I'm looking at it from the perspective of ethics legislation when it comes to AI. If quantum computing will be used in AI technology, is there any concern with regard to the ethics legislation aspect?

Dr. Raymond Laflamme: It would be the same consideration as what you have for classical AI. There would not be a fundamental difference from the ethics point of view.

You might have a difference in how much AI you can do and the speed at which you can process that information, but the result would be fundamentally the same, and the information would be used or manipulated with AI ways of manipulation.

Mr. Han Dong: Does anyone want to jump in with additional comments on this with respect to AI?

Mr. Rafal Janik: Maybe I'll just make one comment.

We have a very large team focused on quantum machine learning and quantum AI applications. A large amount of our software stack is actually focused on that.

I would say there are two types of quantum machine or quantum AI. The first is what we do today. That is really only thought to have an advantage when the data itself is quantum, so when you're looking at materials, chemistry and these types of problems, and maybe it'll be in a few other places, but that's what's believed.

The other is what I would call the end game quantum computer, the one we're all dreaming of when we close our eyes. That one will be able to accelerate fundamental basic operations that will actually speed up machine learning and AI applications. However, this is something that is further out than just a fault-tolerant quantum computer. There are a few additional components to that type of quantum computer that probably put it outside the 15- to 20-year type of road map. I'd say for the next decade or two, the impact of quantum and machine learning AI will probably be limited to problems with quantum data.

[*Translation*]

The Chair: Thank you very much, Mr. Dong.

[*English*]

I want to thank all of you for this great meeting. I think I can speak on behalf of all members of the committee and thank you kindly. It's been very interesting and we've learned a lot, and I think it's important for Canadians to better understand this technology and for governments to be prepared, so thanks for your insight. It's helpful in our study.

I wish you all a very good end of the day.

This meeting is adjourned.